91602
new 82-10

COMPLIMENTARY COPY

ontario hydro
research division

To: Mr. R. A. Sogawa
Manager, Transmission Stations Programs
Design & Development - Transmission

BURLINGTON TS - GROUND GRID INTEGRITY TESTS

R. P. Pillai

Ground grid integrity tests using dc current injection were conducted at Burlington TS in order to evaluate the continuity of the grounding interconnections. Simple models were developed to interpret the measured resistances. Measurements indicated that the grounding interconnections between the various areas at the station are generally in place as per the design drawings.

1.0 INTRODUCTION

Burlington TS is an old 230/115/27.6 kV station and is quite large in size. The station has a non-uniform ground grid with interconnections between grounding meshes of the various HV and LV areas and buildings. New 230/27.6 kV facilities are also being added to the existing facilities. The station staff recently raised concerns regarding the integrity of the existing grounding system, especially the interconnections between the various areas. Therefore, tests were conducted at the station in order to verify the ground grid integrity. It was not practical to check each ground connection at the station due to the large area and the time involved. Furthermore, the integrity of the grounding within a highly meshed area such as 230-kV and 115-kV yards normally should be adequate. Thus, the objective of the test was to determine whether the grounding installations of the various areas and buildings are properly interconnected as per the station design drawings. The project was requested and funded by the Design & Development Division - Transmission. Tests were conducted on April 29, 30, May 1 and 3 of 1991.

job	file	date	report no.
18-215-433	813.521	October 24, 1991	91-258-K

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf

(a) makes any warranty or representation in connection with respect to the accuracy or completeness of the material contained in this report, or that such use does not infringe on or interfere with privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

2.0 TEST PROCEDURE

The grid integrity was tested by circulating a high dc current, typically 100 A, between accessible grid points and measuring the driving point resistance between the points, using a micro-ohmmeter. The instrument is normally used for circuit breaker contact resistance measurements and is compact and reasonably portable. The meter uses a true 4-point measurement method and gives direct reading of the resistance in micro or milli ohms, ranging from 199.9 $\mu\Omega$ to 1999 mΩ full scale. Polarity reversal and averaging of the readings were used to remove the effect of thermal EMF in the measurements. To limit the lead lengths for long distances, the procedure was to leapfrog between nearby grid points until the entire distance between the two areas was covered. The sum of these readings should provide an upper bound to the total resistance between them because meshing of the grid will lower the longitudinal resistance. More than 120 selected measurements were made at the station. Measurements were limited by the accessibility of grid risers, long distances and the time involved.

3.0 INTERPRETATION OF MEASURED RESISTANCES

Figures 1 - 7 which are parts of the station grounding drawing No 51047ES show the measurement locations. Tables 1 to 7 list the measured resistances between the interconnections, along with the corresponding estimated values. Abridged measured results are presented here for simplicity.

The data analysis is complicated due to the non-uniform grid, bridging through overhead steel structures and other uncertainties in the grid installation. Two simple models as follows were developed for an estimate of the resistance between two measurement points. Each measured resistance was then compared with the estimated value to check the continuity of the interconnection. For a proper interconnection, the measured resistances should be less than or reasonably agree with the estimated value. High resistances beyond the 2 Ω measuring capability of the micro-ohmmeter probably indicate no direct bonding, weak connections or complete isolation.

Model A is used for areas with meshed interconnections and Model B is used for longitudinal runs of interconnecting conductor(s). Model A is based on a uniformly meshed ground grid between two areas. It can be shown that the driving point resistance R between two grid points on a large square mesh would be one half of the resistance of the grid conductor between the points. Assuming 170 $\mu\Omega$/m for 107 mm^2 (AWG 4/0) copper grid conductors, the value of R is 85 $\mu\Omega$/m. Other parallel conductive paths such as bridging through overhead steel structures are neglected in the model. Thus for meshed interconnections at the station, the resistance between two measurement points was estimated as the product of 85 $\mu\Omega$/m and the distance between the points. Model B is based on the longitudinal resistance of the length of the interconnecting conductor(s) between buildings or areas and is conservative as meshing of the grid will lower the longitudinal resistance. The distances were estimated from the station grounding drawings and allowances were made to include the grid risers at the measurement points.

3.1 Between 115-kV North and 115-kV South Areas (Figure 1, Table 1)

Measurements show that the two ground grids are interconnected. Resistances over 2 Ω as measured indicate that the 115-kV H-frame grounds (locations 6, 12,19) may not be bonded to the ground grid, as shown in the station drawing. Relatively high resistances were measured on the grounding connections at the lightning tower (location 44).

TABLE 1
MEASURED AND ESTIMATED RESISTANCES
(Between 115-kV North and South Areas)

Measurement Locations	Estimated Distance (m)	Resistance (mΩ) Measured	Resistance (mΩ) Estimated (Model A)
8 - 9	20	1.63	1.70
9 - 10	20	2.82	1.70
10 - 11	20	1.92	1.70
11 - 13	40	3.60	3.40
13 - 7	10	0.88	0.85
7 - 46	20	3.63	1.70
Total: 8-9-10-11-13-7-46	130	14.5	11.1
15 - 16	20	1.88	1.70
16 - 17	20	1.81	1.70
17 - 18	20	1.78	1.70
18 - 20	40	3.96	3.40
20 - 26	10	1.10	0.85
26 - 43	15	1.98	1.28
43 - 42	25	1.37	2.13
Total: 15-16-17-18-20-26-43-42	150	13.87	12.75
31 - 32	20	0.90	1.70
32 - 33	20	0.77	1.70
33 - 34	15	0.94	1.28
34 - 35	50	4.36	4.25
35 - 36	20	2.56	1.70
36 - 37	55	3.24	4.68
37 - 38	20	0.83	1.70
38 - 39	60	6.70	5.10
39 - 40	20	0.93	1.70
40 - 41	20	2.73	1.70
41 - 42	15	1.15	1.28
Total: 31-32-33-34-35-36-37-38-39-40-41-42	315	25.12	26.78
44 - 13	15	2.65	1.28
44 - 20	15	2.40	1.28
44 - 45	10	1.17	0.85

3.2 West of 115-kV South Area (Figure 2, Table 2)

TABLE 2
MEASURED AND ESTIMATED RESISTANCES
(West of 115-kV South Area)

Measurement Locations	Estimated Distance (m)	Resistance (mΩ)	
		Measured	Estimated (Model A)
47- 48	25	2.93	2.13
48 - 49	20	1.08	1.70
49 - 50	15	2.05	1.28
Total: 47-48-49-50	60	6.06	5.10
52 - 53	20	0.83	1.70
53 - 54	15	1.83	1.28
Total: 52-53-54	35	2.66	2.98
57 - 58	20	1.04	1.70
58 - 59	35	2.85	2.98
Total: 57-58-59	55	3.89	4.68
47 - 51	-	2.53	-
47 - 52	40	3.76	3.40
52 - 55	25	2.51	2.13
55 - 57	40	3.15	3.40
55 -56	30	2.40	2.55
55 - 67	-	1.66	-
55 - 68	-	> 2 Ω	-
55 - 68a	-	> 2 Ω	-

The results indicate that the structures west of the station road are all bonded to the main grid. However, the HV structures within the station near the fence line appear to be connected to the station grid only through the skywires. The new structure (location 67) was found bonded to the ground grid.

3.3 Between Old and New Grids in 115-kV South Area (Figure 3, Table 3)

TABLE 3
MEASURED AND ESTIMATED RESISTANCES
(Between Old and New Grids in 115-kV South Area)

Measurement Locations	Estimated Distance (m)	Resistance (mΩ)	
		Measured	Estimated (Model B)
57 - 62	80	4.45	13.6
57 - 63	100	4.87	17.0
62 - 64	150	7.50	25.5
65 - 66	200	12.2	34.0
57 - 61	55	> 2 Ω	9.35
58 - 60	50	> 2 Ω	8.50
60 - 66	50	> 2 Ω	8.50

Measurements in this area were limited by the accessibility due to construction at the time of the tests. Model B in Table 3 assumes single 107 mm^2 conductor between any two measurement points and other parallel paths are ignored for simplicity and conservatism. The considerably lower measured results than the modelled values show that the two areas are interconnected, probably through several parallel paths. Resistances of more than 2 Ω as measured from locations 58 to 60 to 66 and 57 to 61 indicate that the two old 107 mm^2 connections may have been disconnected during the construction. However, new bonding installations between the two areas were visible at the site.

3.4 Between Buildings, 115-kV and 230-kV Yards in the South Area (Figure 4, Table 4)

Thirty-three measurements were made in this area and only selected readings are presented for simplicity. Due to the complex and irregular meshing of the grid conductors in the area, modelling was not attempted in many cases. However, the resistances measured between various points selected at random were all under 2 Ω and indicate that the various buildings and 230-kV and 115-kV yards are all interconnected. Relatively high resistance measured between the microwave tower and the microwave building (between points 77 and 78) indicates that the two grounds are interconnected probably through metallic paths such as cable trays. Resistances over 2 Ω as measured at the microwave building (between points 77, 75 and 76) indicate that the grounding connections may be poor at this location.

TABLE 4
MEASURED AND ESTIMATED RESISTANCES
(Between Buildings and Yards in South Area)

Measurement Locations	Estimated Distance (m)	Resistance (mΩ)		
		Measured	Estimated	
			(Model A)	(Model B)
70 - 69	55	3.28	4.68	-
70 - 71	45	3.31	3.83	-
70 - 72	90	2.53	-	7.65
72 - 79	55	2.47	-	9.35
82 - 79	-	2.98	-	-
76 - 70	-	11.1	-	-
75 - 70	-	> 2 Ω	-	-
77 - 76	-	> 2 Ω	-	-
77 - 75	-	> 2 Ω	-	-
77 - 78	-	14.8	-	-
79-80-81-74-73-91-93-95	-	17.7	-	-
73 - 92	30	4.54	2.55	5.10
95 - 96	35	3.50	-	5.98
95 - 90	-	5.35	-	-
83 - 84	-	1.71	-	-
83 - 87	-	3.07	-	-
83 - 85	80	8.79	6.80	-
83 - 90	-	3.81	-	-

3.5 Interconnections from the Control Building (Figure 5, Table 5)

TABLE 5
MEASURED AND ESTIMATED RESISTANCES
(From Control Building)

Measurement Locations	Estimated Distance (m)	Resistance (mΩ)	
		Measured	Estimated (Model B)
106 - 83	120	3.52	4.33
106 - 77	75	18.3	4.25
106 - 46	120	9.42	20.4
106 - 86	80	13.9	13.6
106 - 107	60	6.86	10.2

The low resistances as measured indicate that the control building is interconnected to the various buildings and yards, as shown in the drawing. The model is based on the straight length of conductor(s) between two measurement points ignoring other parallel paths. Therefore, the modelled longitudinal resistances may be conservative in some cases. The relatively high resistance as measured between the control building and the microwave building (points 106 and 77) indicates that the interconnection may be poor.

3.6 North of Control Building (Figure 6, Table 6)

TABLE 6
MEASURED AND ESTIMATED RESISTANCES
(North of Control Building)

Measurement Locations	Estimated Distance (m)	Resistance (mΩ)		
		Measured	Estimated	
			(Model A)	(Model B)
107 - 112	60	6.10	-	10.2
107-110-111-113-114-115-118	160	14.1	13.6	-
115 - 119	160	4.24	13.6	-
115 - 116	35	5.63	-	5.95
116 - 117	-	6.97	-	-
117 - 120	70	3.55	5.95	-
107 - 108	-	21.8	-	-
107 - 109	-	21.7	-	-

Measurements indicate that the interconnections are in place. The resistances measured between points 107 and 108, and 107 and 109 are relatively high.

3.7 Between 230-kV North and South Areas (Figure 7, Table 7)

TABLE 7
MEASURED AND ESTIMATED RESISTANCES
(Between 230-kV North and South Areas)

Measurement Locations	Estimated Distance (m)	Resistance (mΩ)	
		Measured	Estimated (Model A)
101 - 102	40	1.19	3.40
103 - 104	40	0.86	3.40

The results indicate that the ground grids of the 230-kV south and north yards are interconnected.

3.8 Station Fence Grounding

The resistance measured between the station ground grid and the old fence west of the 115-kV North yard (between points 33 and 33a in Figure 1) was over 2 Ω and the fence may be isolated from the main grid at this location. Similarly, measurements on the new fence around the 115-kV and 230-kV areas at the south west corner of the station indicate that the fence may be isolated from the main station ground grid. However, a resistance of 5.45 mΩ was measured between the old fence and the adjacent HV tower ground west of the 230-kV North yard (between points 122 and 123 in Figure 7). Here, two grounding connections from the tower to the fence were visible. Therefore, the old fence may be connected to the station ground grid at this location and the old and the new sections of the fence are metallically interconnected here.

Some preliminary tests on the new fence on the south side of the station along the railway tracks indicated about 20 A ac circulating current between the fence and the station ground grid at several locations on the fence. The fence is parallel to the 230-kV lines and the induced voltage on the fence may have produced the circulating current due the fence connection to the grid at the far end (points 122 and 123 in Figure 7) as mentioned above. Resistance measurements on the fence using the micro-ohmmeter were not attempted as the circulating current is likely to damage the instrument.

4.0 GENERAL DISCUSSION

(a) Based on the measured results, the integrity of the station ground grid appears adequate in most cases. The differences in the measured and the modelled resistances may be due to the many assumptions made in the simple model and the poor accuracy in estimating the length of conductors. The station design drawing 51047ES does not have a proper scale and the distances were estimated from the drawing based on information from other sources. However, the simple model provides a general criteria for validating the measured results for a low resistance interconnection. A detailed modelling which is complex and time consuming was not considered necessary at this time and is beyond the scope of the project.

(b) The station grounding drawings show that the station fence grounding is isolated from the ground grid. However, measurements indicated that complete metallic isolation of the fence is not achieved. As the station has a railway siding inside, the normal Ontario Hydro practice is to include the fence within the grid. Also, some of the grounded structures inside the fence are within touch distances from the fence which requires the fence to be connected to the ground grid to reduce any touch hazard. In view of this, it may be advisable to include the fence grounding within the main ground grid area.

(c) Ideally, all accessible ground connections and leads at a station should be inspected and tested to ensure proper grid integrity. However, for large stations such as Burlington TS this may be tedious due to the time involved. In the absence of any identified problem area at the station, the measurements were limited to the various interconnections.

(d) The micro-ohmmeter injects a maximum of 100 A dc for a short duration and measures the driving point resistance under 2 Ω between two test points. The method was found convenient and reliable to check the integrity of a ground grid by measuring the global resistance between two grid points. Here, current split measurements using clamp-on current transformers along with the resistance measurements may provide a second criterion to assess proper connections.

(e) The meter was damaged during measurements on the station fence near the 230-kV lines probably due to the large ac circulating current present at the time. Therefore, additional protection is needed for the instrument for use in areas where large ac circulating currents are present.

(f) The micro-ohmmeter method may not accurately check the continuity of an individual grounding conductor. A new method to conveniently trace ground grid conductors is being developed by Ontario Hydro's Research Division. The method is based on monitoring the magnetic field produced by large off-frequency test current (in the order of 100 A).

(g) A high current method (passing large ac test current in the order of 300 - 600 A continuously to stress the grid conductors and measuring the voltage drop and current splits) may be an alternative for detecting weak or faulty ground connections.

5.0 CONCLUSIONS

(a) Measurements indicate that the grounding interconnections are generally in place between various areas at the station.

(b) Relatively high resistances measured at the lightning tower south of the station entrance road (point 44 in Figure 1) and at the microwave building (points 75, 76 and 77 in Figures 4 and 5) indicate that the grounding connections may be poor at these locations.

(c) Measurements indicate that the HV structures within the station near the fence line west of the 115-kV south area appear to be bonded to the station grid only through the skywires. The new structure was found bonded to the ground grid.

(d) The station fence was found connected to the station ground grid at a few locations on the old section of the fence, contrary to the station design drawing.

(e) A visual inspection at the site indicated that the fence grounding was inconsistent or incomplete on the new fence sections.

(f) The micro-ohmmeter method was found convenient and reliable to measure driving point resistances under 2 Ω between two grid points and to check the integrity of a ground grid. However, presence of large ac circulating currents is likely to damage the unit.

6.0 RECOMMENDATIONS

(a) The station fence grounding should be reviewed to include it within the main ground grid.

(b) The fence grounding on the new sections of the station fence should be checked for proper installation as per the design.

(c) The grounding connections at the lightning tower (location 44 in Figure 1) and at the microwave building should be checked, as relatively high resistances were measured at these locations.

(d) The micro-ohmmeter method may be used by station maintenance staff to check grounding connections. Precautions should be taken to see that ac circulating currents do not damage the instrument.

(e) Further work is needed in developing additional protection for the micro-ohmmeter for its use in areas where large ac circulating currents are present.

(f) Further work is needed in developing a detailed model to take into account the irregularity of the ground grid, bridging though steel structures, etc.

(g) Alternative methods to check the continuity of individual grounding conductors and to detect weak or faulty connections as mentioned in section 4.0 should be studied.

Approved:

A.F. Baljet
Manager
Electrical Research Department

Submitted:

R.P. Pillai
Engineer
System Studies Section

REFERENCES

1. Memorandum dated October 3, 1990 from Mr. P. Thomason, Burlington TS P&C to Mr. S. Sahin, Transmission Stations Programs Department.

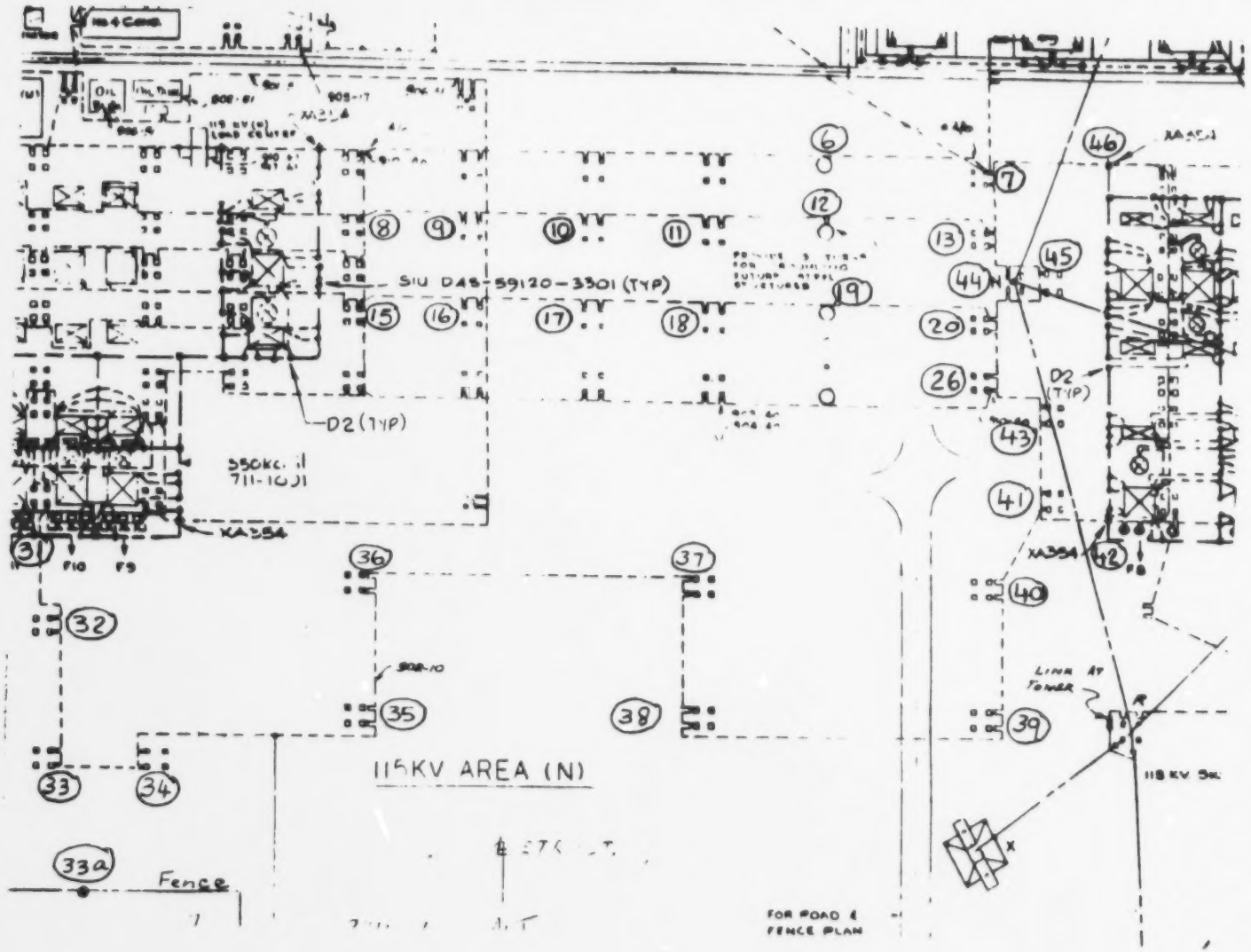

Figure 1

Burlington TS Grounding Layout
With Respect to Grid Integrity Tests
(Between 115-kV North & South Areas)

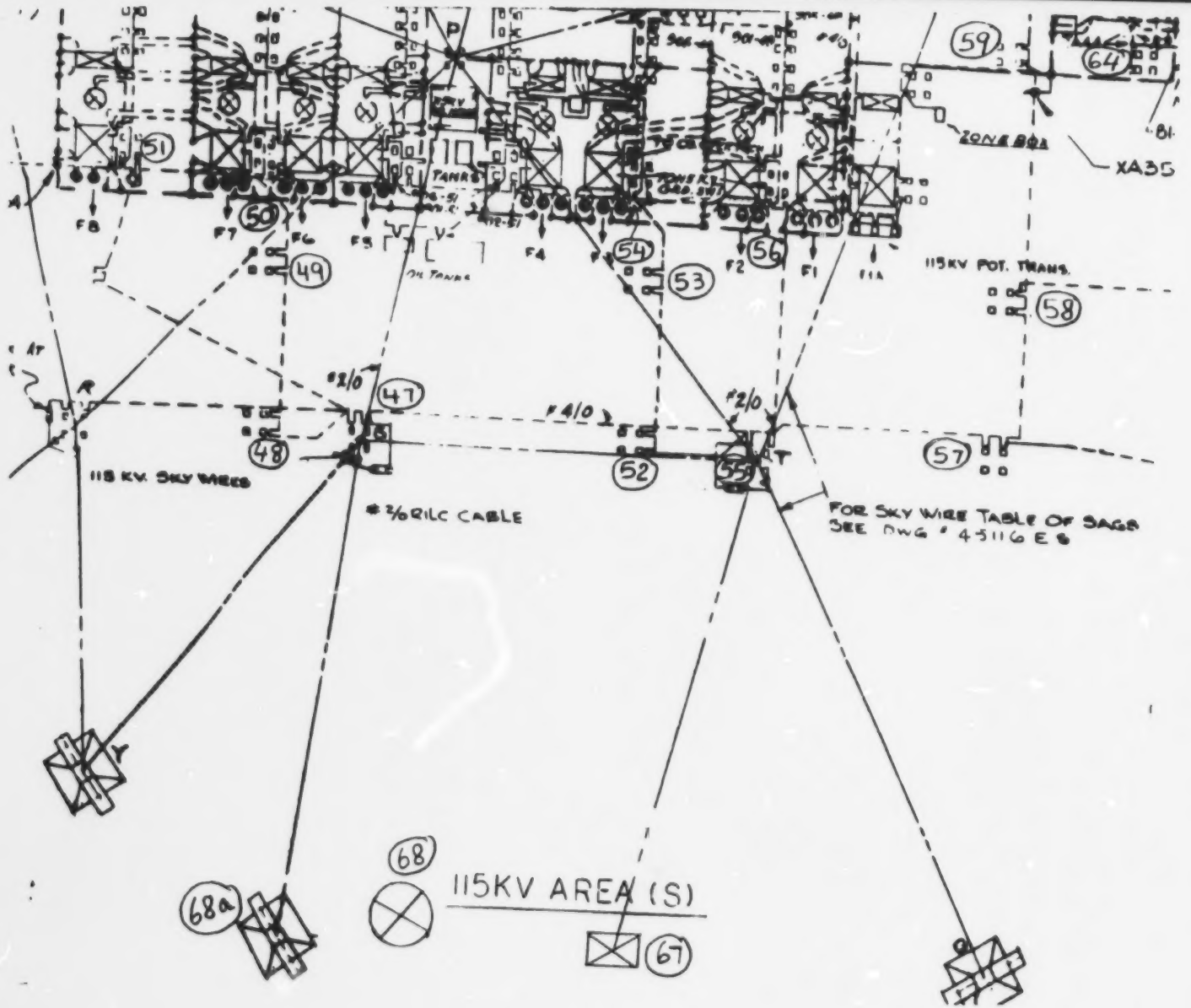

Figure 2

Burlington TS Grounding Layout
With Respect to Grid Integrity Tests
(West of 115-kV South Area)

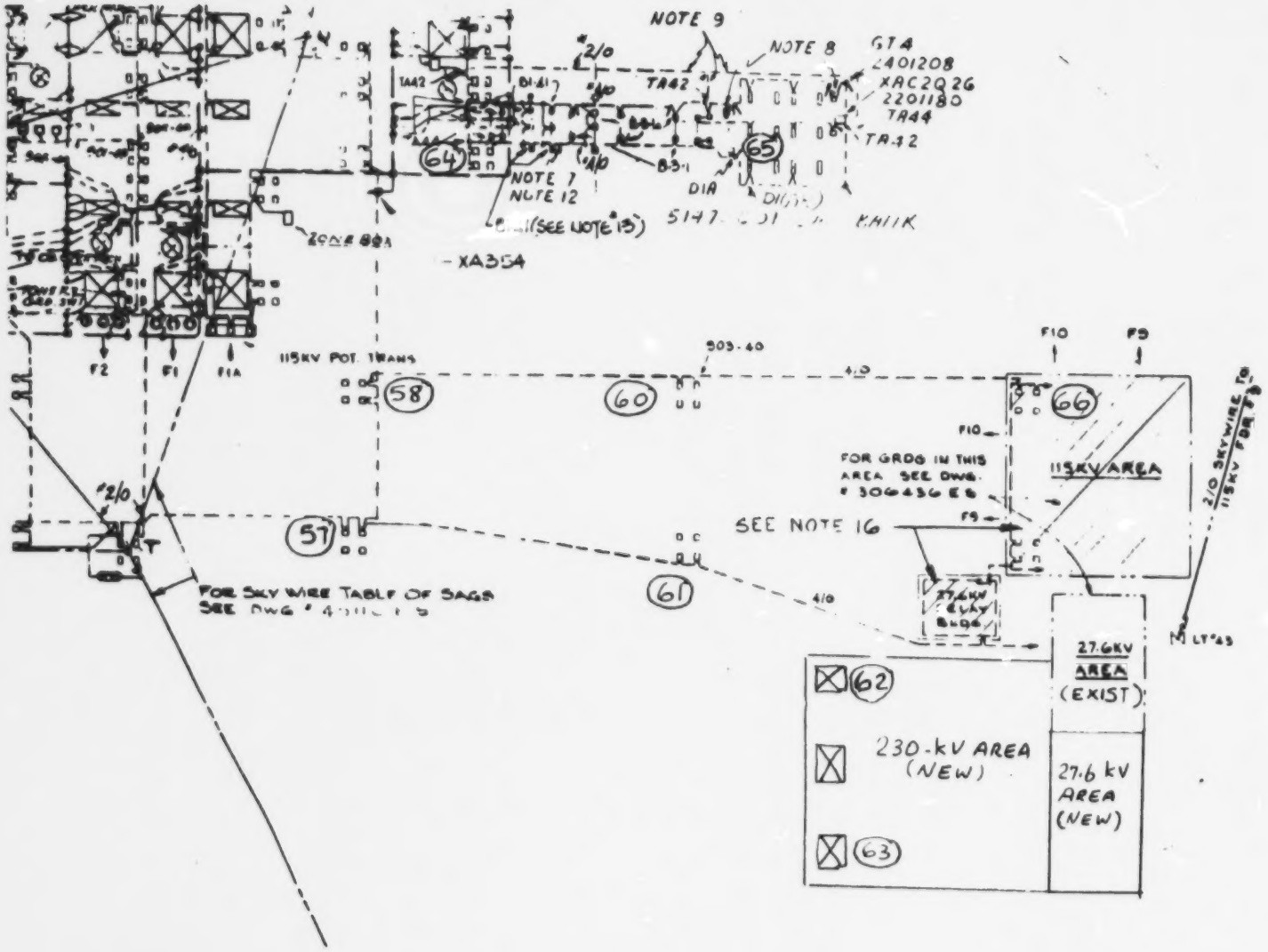

Figure 3

Burlington TS Grounding Layout
With Respect to Grid Integrity Tests
(Between Old & New Grids)

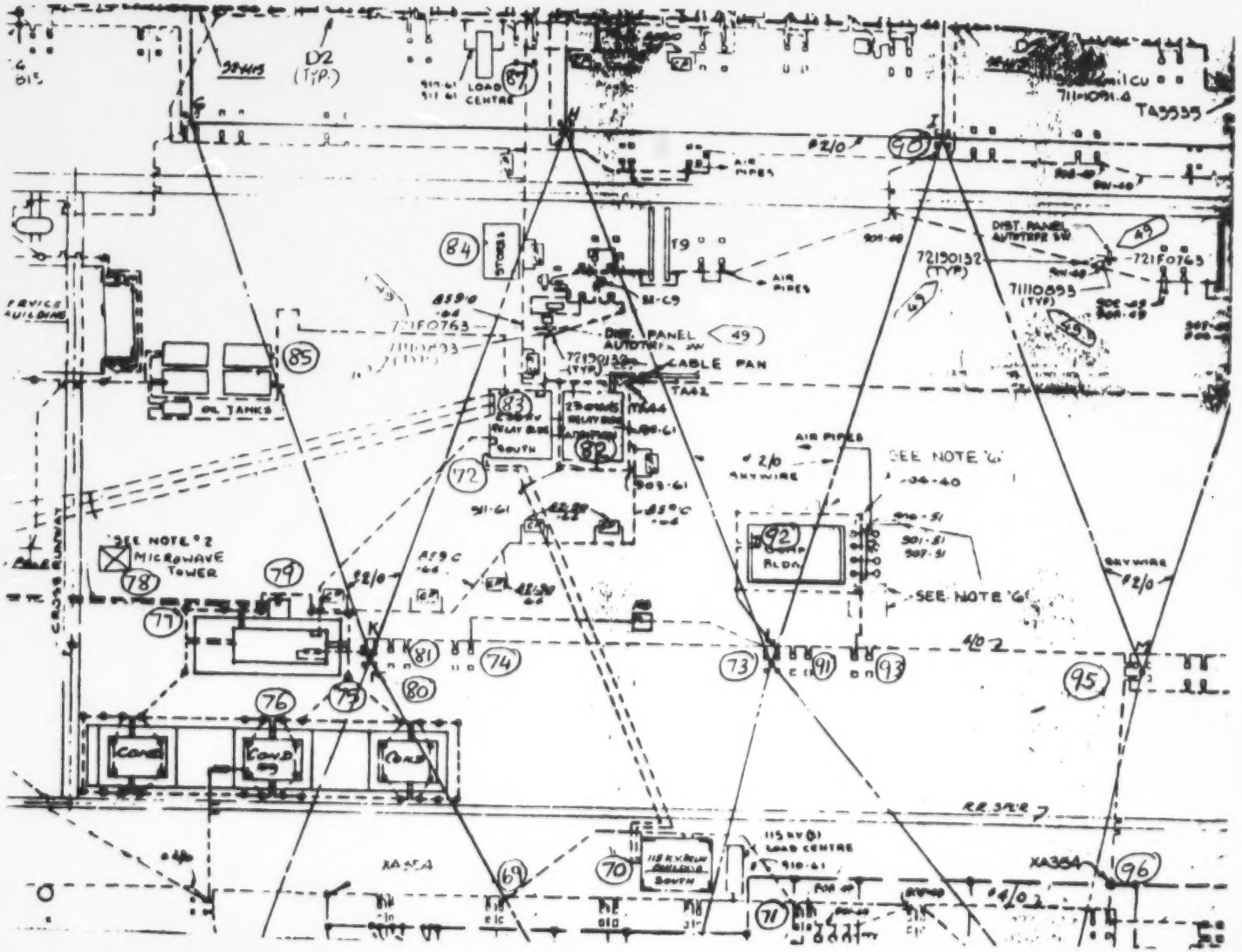

Figure 4

Burlington TS Grounding Layout
With Respect to Grid Integrity Tests
(Between Buildings & Yards in South Area)

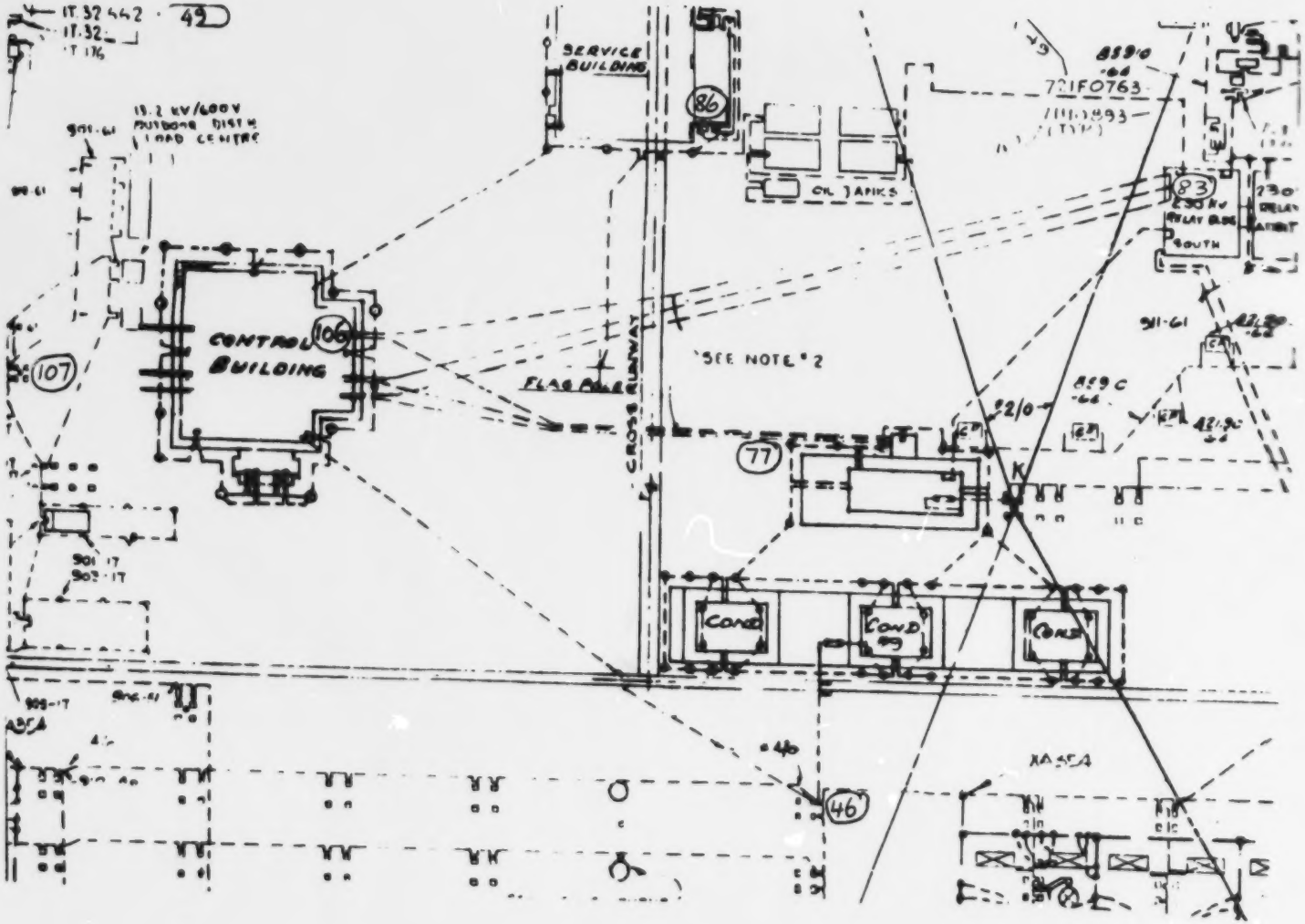

Figure 5

Burlington TS Grounding Layout
With Respect to Grid Integrity Tests
(From Control Building)

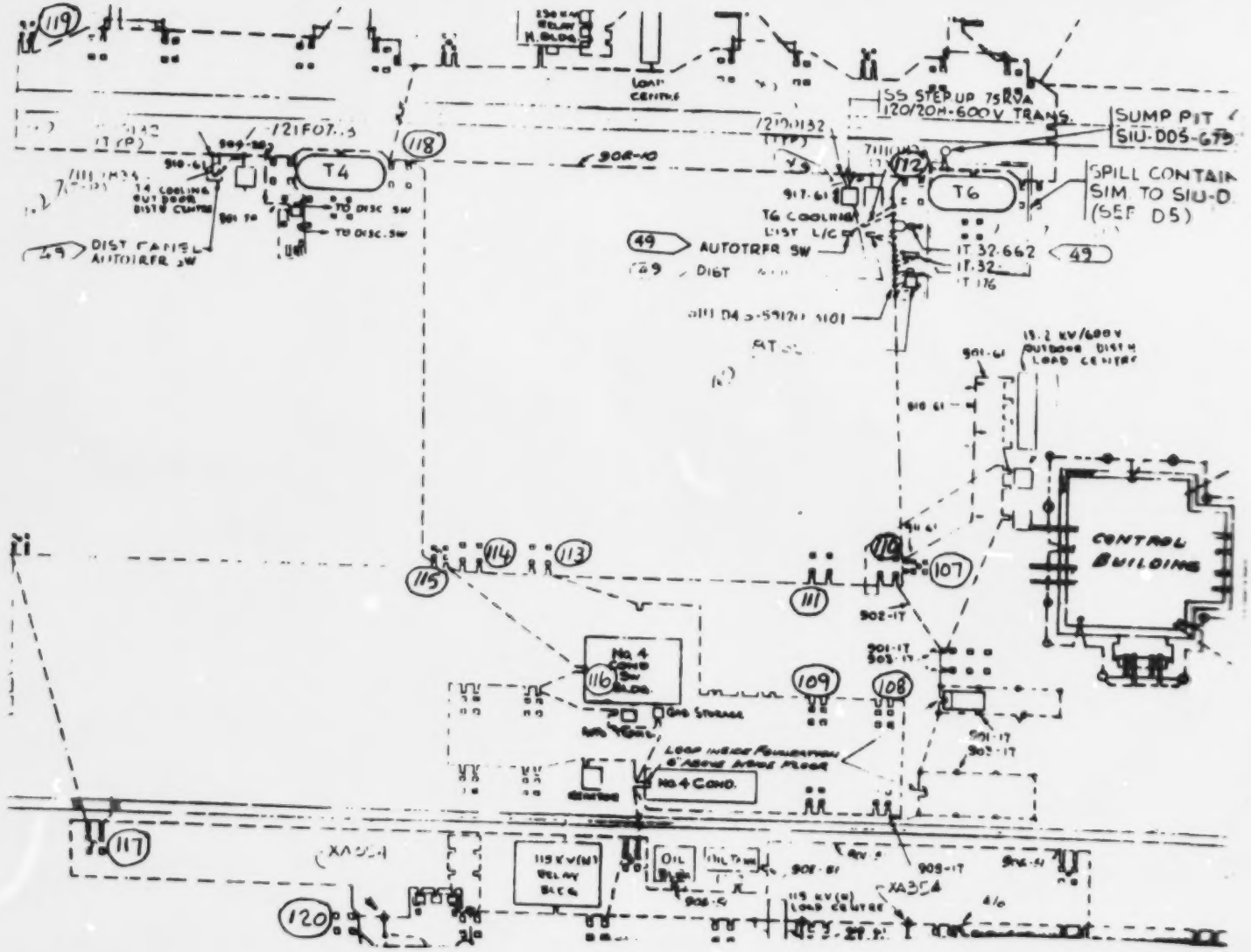

Figure 6

Burlington TS Grounding Layout
With Respect to Grid Integrity Tests
(North of Control Building)

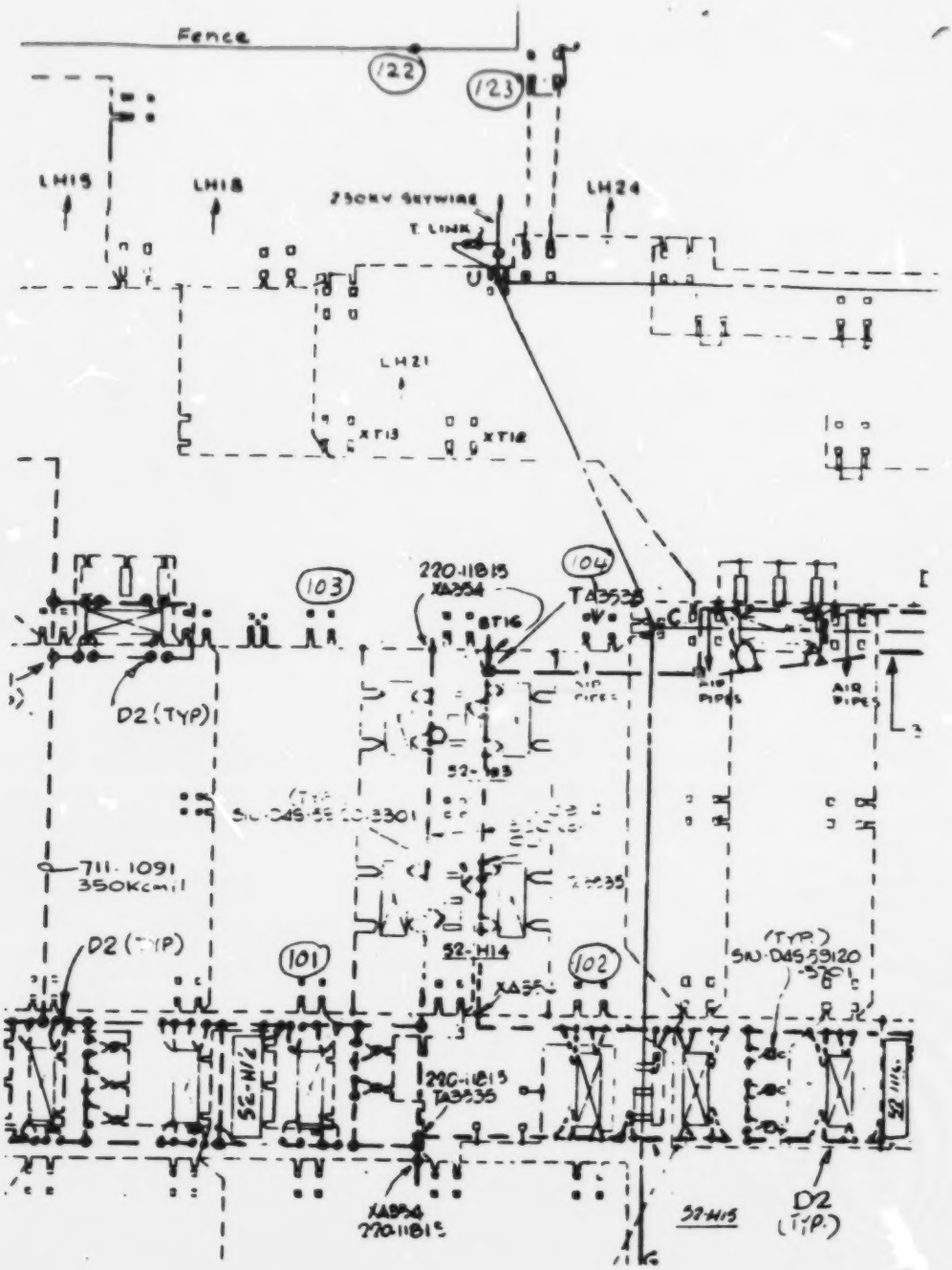

Figure 7

Burlington TS Grounding Layout
With Respect to Grid Integrity Tests
(Between 230-kV North & Sourth Areas)